Net absorption and utilization of nitrogenous compounds across ruminal, intestinal, and hepatic tissues of growing beef steers fed dry-rolled or steam-flaked sorghum grain

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J Anim Sci 2002. 80:525-532.

Net absorption and utilization of nitrogenous compounds across ruminal, intestinal, and hepatic tissues of growing beef steers fed dry-rolled or steam-flaked sorghum grain[1,2]

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ABSTRACT: Our objectives were to determine effects of grain processing on splanchnic (gut tissues and liver) N metabolism and whole-body N balance by growing steers and to ascertain the relative contributions of ruminal and intestinal tissues to net absorption and utilization of N-containing nutrients. Seven beef steers (348 kg initial BW), surgically implanted with appropriate catheters, were fed diets containing 77% steam-flaked (SF) or dry-rolled (DR) sorghum grain. Blood flows and net output or uptake of ammonia N, urea N, and α-amino N (estimate of amino acids) were measured across portal-drained viscera (PDV or gut tissues) and intestinal, ruminal, hepatic, and splanchnic tissues (PDV + hepatic). The experimental design was a crossover between DR and SF diets, with six samplings of blood at 2-h intervals on 2 d for each steer. Nitrogen intake (139 ± 3 g/d), output in urine (43 ± 2 g/d), and retention (40 ± 3 g/d) were similar for both processing treatments. When steers were fed SF sorghum compared to DR sorghum, N retention as a percentage of N intake was numerically greater ($P < 0.12$), output of fecal N was numerically lower ($P < 0.13$), and urinary urea N was lower ($P < 0.04$). For SF vs DR, net uptake of α-amino N by liver was higher ($P < 0.04$; 20 vs 9 g/d) and was numerically lower ($P < 0.16$) for ruminal tissues (15 vs 33 g/d). Feeding steers SF compared to DR tended to increase net transfer (cycling) of blood urea N to PDV (57 vs 41 g/d; $P < 0.07$), increased cycling to intestinal tissues (15 vs 6 g/d; $P < 0.05$), and numerically increased transfer to ruminal tissues (42 vs 32 g/d; $P < 0.12$) but did not alter other net output or uptake of N across splanchnic tissues. Total urea N transfer (blood + saliva) was similar for both treatments. Net uptake of α-amino N by ruminal tissues was about 30% of the net amount of α-amino N absorbed across the intestinal tissues. In summary, most of the blood urea N cycled from the liver to gut tissues was transferred to ruminal tissues for potential microbial protein synthesis, and the net ruminal utilization of α-amino N was about 30% of that absorbed from intestinal tissues. Feeding growing steers SF compared to DR sorghum diets numerically increased whole-body N retention (percentage of N intake) by about 15% and tended to increase transfer of blood urea N to the gut by about 40%, which could increase the supply of high-quality microbial protein for absorption.

Key Words: Beef Cattle, Grain, Nitrogen Metabolism, Processing

 J. Anim. Sci. 2002. 80:525–532

Introduction

Net absorption of N in ruminants fed growing-finishing diets is characterized by large amounts of ammonia that is converted to urea by the liver. If the amount of liver urea production transferred (cycled) to the rumen can be enhanced, rather than lost in the urine, the N economy of high-producing animals should be enhanced. Increasing amounts of readily fermentable carbohydrate to the rumen increased urea cycling to the rumen (Kennedy and Milligan, 1980; Huntington, 1989) and decreased urea transfer to postgastric tissues (Reynolds and Huntington, 1988). Shifting a greater

[1]The authors gratefully acknowledge Elinor Zetina, Joanne Whitt, Ben Stroud, Kathleen McLaughlin Phalen, Ted Currier, Vince Beal, Armando Baez, Matthew Poore, Tom Eck, Heba Shaaban, and Robert Drake for their technical assistance and L. George-Smith for manuscript preparation.

[2]Partially supported by Texas Grain Sorghum Board, Abernathy, TX.

Received August 11, 2000.

Accepted August 2, 2001.

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[6]Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

Table 1. Composition of diets[a]

Ingredient	% DM
Sorghum grain (DR or SF)[b]	77.0
Alfalfa hay	15.0
Cottonseed meal	2.3
Cane molasses	4.0
Limestone	0.9
Trace mineralized salt[c]	0.5
Urea	0.3

[a]89% DM. Percentage of DM: CP, 12.1%; starch, 58.4%; DE, 2.99 (DR) or 3.28 (SF) Mcal/kg.
[b]DR = dry-rolled; SF = steam-flaked (257 g/L or 20 lb/bu).
[c]96% NaCl, 0.2% Mn, 0.1% Fe, 0.1% Mg, 0.05% S, 0.025% Cu, 0.01% Co, 0.008% Zn, and 0.007% I.

proportion of total starch digestion from the small intestine to the rumen seems to result in greater supply of microbial protein to the duodenum of beef and dairy cattle (Theurer et al., 1996, 1999a). Steam-flaking of both corn and sorghum grain (compared to steam-rolling, dry-rolling, or grinding of these grains) is an effective mechanism for shifting a higher proportion of starch digestion from the intestines to the rumen of cattle (Theurer, 1986; Huntington, 1997; Theurer et al., 1999a).

We hypothesized that increasing the proportion of starch digested in the rumen (by steam-flaking) would increase the amount of urea transferred to the rumen, thus increasing the supply of microbial protein and whole-body N retention by growing steers. One objective of this study was to characterize changes in response to grain processing (steam-flaked [**SF**] vs dry-rolled [**DR**] sorghum) on net uptake or output of ammonia N, α-amino N (estimate of amino acids), and urea N across splanchnic tissues (portal-drained viscera; [**PDV** or gut tissues] and liver tissues) and to integrate these changes with whole-body N balance of growing steers. Another objective was to measure the relative contributions of ruminal and intestinal tissues to net absorption and utilization of these metabolites.

Materials and Methods

Animals and Diets

This experiment was conducted under the approval and supervision of the USDA Beltsville Animal Care Committee. Seven Hereford × Angus steers (348 kg initial BW) were fed alfalfa silage and a supplement containing grain, vitamins, and minerals for the 4 mo between weaning and castration and the start of the experiment. Intake was controlled to provide approximately 0.75 kg/d BW gain during this period. Before surgery, steers were adapted to the experimental diets (Table 1). Each steer was offered either DR or SF sorghum to determine voluntary DMI.

At least 4 wk before surgery the steers were moved to individual pens that were used during the experiment. The indoor pens were 1.8 × 3.6 m, had outdoor exercise lots of about the same dimensions, and had individual water cups. Steers were fitted with head halters that were attached with chains to their feed and water supply. Overhead, incandescent lighting was on 16 h and off 8 h daily. Throughout the experiment, steers were weighed twice weekly and allowed daily exercise outdoors unless preempted by their sampling protocol. Feed offered and orts were weighed daily.

Chronic catheters were placed in the abdominal aorta or mesenteric artery and in venous sites to allow sampling of blood draining the mesenteric-drained viscera (or intestinal tissues), PDV, and liver (Huntington, 1989; Huntington et al., 1989). Catheters were placed in distal mesenteric veins for infusion of blood flow marker (*para*-aminohippurate). There were at least 2 wk of recovery from surgery before the first sampling. During that period, steers were fed the experimental diet and accustomed to equipment, personnel, and protocol by participation in practice sessions. Average BW and age ± SD at first sampling were 348 ± 19 kg and 12.3 ± 0.9 mo, respectively.

Sorghum grain (9% H_2O) was steam-processed in an upright and open steam chamber for 60 min and flaked through preheated 61- × 76-cm corrugated steel rollers to a flake density of 257 g/L (20 lb/bu) as described by Swingle et al. (1999). Moisture content of the grain as it left the rollers was 13.5%. Although moisture content of grain as it leaves the roller should usually exceed 18%, additional steaming time did not increase moisture content of the whole grain to more than 13.5%. Thus, the steamed grain was flaked to a very light density to ensure proper alteration of protein and starch in the grain kernel. The flaked grain was sun-dried to about 10% moisture. The DR sorghum came from the same lot as the SF sorghum, and preparation was described by Theurer et al. (1999b). The DR and SF grains were placed in cardboard barrels and shipped from Tucson, AZ to Beltsville, MD for the animal study.

Experimental diets (Table 1) contained 77% DR or SF sorghum, chopped alfalfa hay, and a supplement (urea, molasses, cottonseed meal, ground limestone, trace-mineralized salt, and vitamin A to provide 2,200 IU/kg total diet). The diet met or exceeded steers' requirements (1 kg/d gain) for energy, protein, vitamins, and minerals (NRC, 1984). The sorghum grain, hay, and supplement were weighed and mixed daily for each steer. Diets were fed by automated feeders that dispensed a meal every 12 h (0800 and 2000). Feed intake during the experiment was adjusted to maximize DMI yet minimize orts for either diet. Intake of DM for each steer was usually similar for both diets (Table 2), but occasionally voluntary intake would be 10 to 20% more (or less) than the previous diet. The amounts of diets fed were held constant for at least 7 d prior to each blood sampling. Each steer received both dietary treatments, which were randomly assigned. Following the first diet, each steer was switched to the other diet. The experimental design was a balanced crossover with 2 wk between blood samplings for each treatment.

Table 2. DM and DE intakes and nitrogen metabolism by steers fed dry-rolled or steam-flaked sorghum grain diets[a]

Item	Dry-rolled	Steam-flaked	SEM	$P <$
DM intake, g/d	7,316	7,133	162	0.46
DE intake, Mcal/d	21.8	23.4	0.6	0.15
Nitrogen				
Intake, g/d	141.2	137.7	3.2	0.47
Fecal, g/d	59.8	53.7	2.4	0.13
Urinary, g/d	43.9	41.2	1.7	0.30
Urea N, g/d	25.5	21.2	1.1	0.04
Urea N, g/100 g urine	0.35	0.28	0.01	0.01
Digestibility, %	57.8	61.4	1.6	0.17
Retained				
g/d	37.6	42.8	2.8	0.24
% N intake	26.7	31.3	1.7	0.12
% N absorbed	46.1	50.9	2.1	0.16

[a]Means are based on seven steers per treatment.

Sampling and Analytical Procedures

Daily grab samples of grain, hay, and supplement were composited weekly for analysis. Blood samples were collected on 2 d (with 1 d hiatus) every 2 h between 0800 and 1800. At least 30 min before sampling, a primed, continuous infusion of *para*-aminohippurate into a distal mesenteric vein began. Approximately halfway through the experiment, the infusion rate was increased from 6,420 mg/h to 9,000 mg/h in order to maintain adequate levels of *para*-aminohippurate in blood samples (Huntington et al., 1989). Simultaneous samples were collected from arterial and mesenteric, portal, and hepatic vein catheters into heparinized, 10-mL syringes and placed on ice until analysis. Blood concentrations of *para*-aminohippurate, ammonia N, urea N, and α-amino N were determined on fresh samples by procedures described previously (Huntington, 1984; Eisemann et al., 1987).

A 5-d collection of urine and feces was conducted before, during, and after the 2-d blood sampling while steers were restricted to an 0.8- $\times$ 2.6-m space by placing a temporary panel in the pen. Urine was aspirated from a urinal that was strapped to steers and collected in plastic jugs that contained sufficient HCl to maintain a pH of 3. Feces were collected several times daily and stored in plastic containers. Urine and fecal output were measured daily, and an aliquot was retained for subsequent analysis. Samples of feeds, orts, and feces were ground (Swingle et al., 1999); these samples and urine were analyzed for N content by Kjeldahl procedures (AOAC, 1984). Urinary concentration of urea N was measured using the same procedure as that used for blood. Dry matter (AOAC, 1984), gross energy by adiabatic bomb calorimetry (Parr Model 1241, Moline, IL), and total starch (Poore et al., 1991) were determined on feeds, orts, and feces.

Calculations and Statistical Analyses.

Tissues of the PDV (gut tissues) include the total digestive tract, pancreas, spleen, and mesenteric fat. Intestinal tissues (poststomach or mesenteric-drained viscera) include small intestine, cecum, large intestine, mesenteric fat, and pancreas. Ruminal tissues include rumen, reticulum, omasum, abomasum, upper duodenum, spleen, and pancreas (Reynolds and Huntington, 1988). Blood flow and net uptake or output of metabolites across PDV and intestinal, liver, and total splanchnic tissues were calculated as described by Huntington (1989). Ruminal tissue values for each steer were PDV values minus intestinal tissue values. Ruminal uptake of N from saliva was calculated as splanchnic urea N output minus urinary urea N output.

For statistical analysis of data, means were calculated within steer and treatment. The General Linear Models procedures of SAS (SAS Inst. Inc., Cary, NC) were used to analyze data in a model that included steer and diet as main effects, tested against residual mean squares. The statistical model was $Y_{ij} = \mu + T_i + S_j + e_{ij}$, where Y_{ij} = observation, μ = overall mean for each metabolite, T_i = diet effect, S_j = steer effect, and e_{ij} = random error. Statistically significant differences between treatments were declared for $P = 0.05$ and a tendency for $0.05 > P < 0.10$. Because we were unable to obtain complete sets of samples for each sampling day, there are missing data; n ranges from five to seven for a given dependent variable, and least squares means are presented in tables.

Results and Discussion

Nutrient Intakes, Retention, Blood Flows, and N Concentrations

Dry matter intakes (7.2 ± 0.2 kg/d) did not differ when steers were fed DR compared to SF treatments (Table 2). Grain processing treatment did not alter measured DE intake. Calculated ME intakes (NRC, 1984) were 20.7 and 21.8 Mcal/d for DR and SF, respectively.

Steam-flaking decreased urea N output, but not total N, in the urine of growing beef steers. Daily (g/d) N intake, output in urine, and retention did not differ

Table 3. Blood flow and concentrations of nitrogenous compounds in blood by steers fed dry-rolled or steam-flaked sorghum grain diets

Item	Dry-rolled	Steam-flaked	SEM[a]	*P*
Blood flow, L/h				
Mesenteric vein (M)	336 (5)[b]	413 (5)	70	0.50
Ruminal (P-M)	491 (5)	455 (5)	70	0.75
Portal vein (P)	859 (6)	894 (6)	40	0.58
Hepatic vein	1,071 (5)	1,052 (7)	47	0.77
β-Amino N, m*M*				
Arterial	2.67 (6)	2.77 (7)	0.06	0.26
Mesenteric vein	3.35 (6)	3.11 (6)	0.14	0.31
Portal vein	2.78 (6)	2.84 (6)	0.06	0.57
Hepatic vein	2.71 (5)	2.81 (7)	0.09	0.46
Ammonia N, m*M*				
Arterial	0.42 (6)	0.43 (7)	0.01	0.82
Mesenteric vein	0.70 (6)	0.63 (6)	0.05	0.40
Portal vein	0.61 (6)	0.61 (6)	0.01	0.80
Hepatic vein	0.41 (5)	0.42 (7)	0.01	0.84
Urea N, m*M*				
Arterial	3.64 (6)	3.10 (7)	0.13	0.03
Mesenteric vein	3.63 (6)	3.00 (6)	0.14	0.04
Portal vein	3.50 (6)	2.90 (6)	0.13	0.04
Hepatic vein	3.85 (5)	3.18 (7)	0.14	0.02

[a]Used larger SEM with unequal number of observations.
[b]Parenthetical numbers equal number of observations.

between treatments (Table 2); however, when steers were fed SF compared to DR, daily output of urea N in the urine was 17% lower ($P < 0.04$), reflecting a lower ($P < 0.01$) urinary urea N concentration. Steers fed SF numerically decreased ($P < 0.13$) daily fecal N output by 10% and numerically increased ($P < 0.12$) N retention as a percentage of intake by 17%. We expected an increase in N retention, because efficiency of gain is improved for feedlot steers fed SF sorghum (Hale, 1980) and SF corn (Barajas and Zinn, 1998; Zinn et al., 1998) compared to DR grains. To our knowledge, no other studies have determined N balance of growing steers fed SF compared to DR sorghum grain diets. Our data support that of Taniguchi et al. (1995), who found that supplying more starch to the rumen compared to the abomasum increased N retained and decreased urinary urea N excretion by steers.

The effects of increasing ruminal starch supply or digestibility on CP digestibility are variable. Steam-flaking increased starch digestibility in these steers (Theurer et al., 1990), but digestibility of N was not altered by treatment (Table 2). Rahnema et al. (1987) reported an increase in CP digestibility when steers were fed SF vs DR sorghum, but Theurer et al. (1999b) found no effect on CP digestibilities by feeding steers DR compared to SF sorghum (average of three flake densities). Taniguchi et al. (1995), reported that increasing starch supply to the rumen increased N digestibility compared to increasing abomasal starch supply.

Blood flows (L/h) for mesenteric (374 ± 70), portal (876 ± 40), and hepatic (1,062 ± 47) veins and across ruminal tissues (portal minus mesenteric; 473 ± 70) were similar for both diets (Table 3). Feeding diets similar to the present study, containing SF (437, 360, or 283 g/L or 34, 28, or 22 lb/bu) compared to DR sorghum, tended to decrease portal, but not hepatic, blood flow of growing steers (Alio et al., 2000). In the present study, the proportion of hepatic flow accounted for by portal flow (0.86 ± 0.03) did not vary with grain processing and was similar to that reported by others (Huntington, 1989; Huntington et al., 1996; Alio et al., 2000). The proportion of portal flow accounted for by intestinal flow (0.44 ± 0.07) also did not differ between treatments and was similar to the range of 0.34 to 0.42 obtained in other studies (Reynolds and Huntington, 1988; Huntington, 1989; Huntington et al., 1996).

Mean blood concentrations of α-amino N and ammonia N in arterial and mesenteric, hepatic, and portal veins were not altered by diet (Table 3). Venous arterial concentration differences are not shown, but were determined for each steer and treatment. Mean venous arterial concentration differences may be determined from Table 3. Concentrations of urea N were approximately 17% lower ($P < 0.04$) in all blood sources when steers were fed the SF diet compared to the DR diet. Because blood flows were similar between dietary treatments, changes in net output or uptake of α-amino N and urea N across tissues measured (Table 4) largely reflect venous-arterial concentration differences for these metabolites.

α-Amino Nitrogen

Steam-flaking of sorghum grain markedly increased ($P < 0.04$) the uptake of α-amino N (estimate of amino acids) by the liver but did not alter net PDV or gut

tissue absorption or splanchnic output. Net absorption of α-amino N across intestinal tissues and PDV did not differ between diets (Table 4). For SF compared to DR, net ruminal tissue uptake of α-amino N was numerically lower ($P < 0.16$) by about one-half, and net hepatic uptake doubled ($P < 0.04$). Spanchnic output or supply of α-amino N to extrasplanchnic tissues was not altered by diet (15 ± 5 g/d). The uptake of α-amino N by the liver was 46 and 27% ($P = 0.06$; calculated from individual steer values, not shown), respectively, of the net absorption across intestinal tissues when steers were fed SF compared to DR sorghum. In contrast, Alio et al. (2000) reported that hepatic uptake of α-amino N was not altered by steers fed similar diets when comparing DR and SF sorghum. The lack of changes in net absorption of α-amino N across the PDV and net output by splanchnic tissues was also shown by Alio et al. (2000). Shifting a greater proportion of total starch digestion from the small intestine to the rumen seems to result in greater supply of microbial N to the duodenum of beef and dairy cattle but does not consistently alter total N reaching the small intestine (Theurer et al., 1996, 1999a). Although feeding SF vs DR did not alter net absorption of α-amino N in our study, amino acid composition may have been altered to reflect greater microbial protein supply to the intestinal tissues.

Net absorption of α-amino N across intestinal tissues in the present study averaged about 40% of N intake (calculated from Tables 2 and 4), which is similar to values of 43 and 49% for steers fed high-concentrate diets in studies by Huntington (1989) and Huntington et al. (1996), but is much lower than values (77%) reported by Reynolds and Huntington (1988), who sampled to emphasize the meal effect. In the present study, only about 11% of N intake by steers was released by splanchnic tissues as α-amino N for use by extrasplanchnic tissues (i.e., muscle, brain, etc.). Our value seems low compared to the mean value of 18% for steers fed DR and SF sorghum in the study by Alio et al. (2000) or the mean of 20 to 24% for steers fed 63 to 78% corn diets (Huntington, 1989; Huntington et al., 1996). The reason for our low value is not know but may reflect differences in meal patterns (12 times daily) for the latter two studies.

Net uptake of α-amino N by ruminal tissues (from arterial blood) is almost one-third the net amount of α-amino N absorbed across intestinal tissues. In the present study, ruminal uptake of α-amino N expressed as a proportion of net absorption across intestinal tissues averaged 30 ± 4% for both treatments. Corresponding values for steers fed 63 to 78% corn diets ranged from 24 to 36% (calculated from data of Reynolds and Huntington, 1988; Huntington, 1989; and Huntington et al., 1996).

The relationship between rumen fermentability of DM or starch compared to ruminal tissue uptake of amino acids is not clear. In the present study, ruminal tissue uptake of α-amino N numerically decreased on the diet with highest starch fermentability (Theurer, 1986; Huntington, 1997; Theurer et al., 1999b). Steers fed high-concentrate (63 to 78% corn) compared to high-forage diets had similar ruminal tissue uptake of α-amino N in two studies (Huntington, 1989; Huntington et al., 1996) but greater uptake in one study (Reynolds

Table 4. Net output or uptake[a] of nitrogenous compounds across splanchnic tissues of steers fed dry-rolled or steam-flaked sorghum grain diets

Item[b]	Dry-rolled	Steam-flaked	SEM[c]	*P*
α-Amino N flux, g/d				
Intestinal tissues	66.2 (5)[d]	48.7 (5)	9.4	0.30
Ruminal tissues	–32.6 (5)	–15.1[e] (5)	6.4	0.16
PDV (gut tissues)	30.2 (6)	33.6 (6)	5.0	0.66
Hepatic tissues	–8.7 (5)	–20.2 (6)	2.4	0.04
Splanchnic tissues	14.8[e] (5)	16.1 (7)	5.4	0.82
Ammonia N flux				
Intestinal tissues	28.2 (5)	27.6 (5)	1.3	0.81
Ruminal tissues	20.2 (5)	27.6 (5)	4.7	0.39
PDV (gut tissues)	53.1 (6)	56.1 (6)	4.7	0.72
Hepatic tissues	–62.2 (5)	–59.1 (6)	2.4	0.45
Splanchnic tissues	3.0 (5)	–3.7 (7)	0.7	0.55
Urea N flux, g/d				
Intestinal tissues	–5.7[e] (5)	–14.8 (5)	2.0	0.05
Ruminal tissues	–32.3 (5)	–42.3 (5)	3.4	0.12
Salivary[f]	–13.3 (5)	–2.0[e] (7)	6.4	0.22
PDV (gut tissues)	–41.3 (6)	–57.4 (6)	4.7	0.07
Hepatic tissues	84.3 (5)	79.2 (6)	10.8	0.77
Splanchnic tissues	39.3 (5)	23.2 (7)	7.7	0.17

[a]Positive values indicate net absorption, synthesis, or output and negative values indicate net uptake.
[b]PDV = portal-drained viscera or gut (ruminal + intestinal).
[c]Used larger SEM with unequal number of observations.
[d]Parenthetical number equals number of observations.
[e]Mean is not different from zero ($P < 0.05$).
[f]Splanchnic urea N output minus urinary urea N output.

and Huntington, 1988); however, in the latter study, ruminal tissue uptake for the forage diet was much lower than in subsequent published studies.

Ammonia Nitrogen

Processing method (SF vs DR) did not alter net uptake or output of ammonia N across any tissues measured (Table 4). Other studies comparing effects of grain processing (Alio et al., 2000) or grain source (Gross et al., 1988) also found no differences in ammonia N metabolism across PDV, hepatic, or splanchnic tissues. In contrast, Taniguchi et al. (1995) found more net ammonia absorption across PDV by steers when starch was supplied to the rumen compared to increasing the amount of abomasal starch. Net absorption of ammonia N across PDV usually exceeds net absorption of α-amino N. The ratio of absorbed ammonia N to absorbed α-amino N for the present experiment was 1.7 (derived from Table 4), 1.1 for the study of Alio et al. (2000), who compared SF to DR, and 1.2 to 1.4 for steers fed high-concentrate diets (Reynolds and Huntington, 1988; Huntington, 1989; and Huntington et al., 1996).

The net amount of ammonia N absorbed from intestinal tissues may be equal to or exceed that absorbed from ruminal tissues of beef steers fed high-concentrate diets (present study; Reynolds and Huntington, 1988) or may be 50% or less than that absorbed from ruminal tissues (Huntington, 1989; Huntington et al., 1996). The reason for this wide variability is not known but probably relates to degradability of N in the rumen and quantity and quality of protein (amino acid profile) supplied to the intestines.

Urea Nitrogen

Steam-flaking of sorghum markedly increased the amount of blood urea transferred from the liver (site of synthesis) to both ruminal and intestinal tissues. Although hepatic synthesis of urea N did not differ between diets (82 ± 11 g/d), transfer of blood urea N to PDV was almost 40% greater ($P < 0.07$) when steers were fed SF vs DR (Table 4). This was because of a greater ($P < 0.05$) cycling of blood urea N to intestinal tissues and a numerically greater transfer ($P < 0.12$) to ruminal tissues through the rumen wall. Transfer of urea N via saliva (8 ± 6 g/d) was not different for DR and SF. The SF value was not different from zero. Thus, total transfer of endogenous urea N to ruminal tissues (via rumen wall and saliva) was similar for both treatments (45 g/d). Alio et al. (2000) reported that feeding steers SF (average of three flake densities) compared to DR sorghum did not alter the amount of blood urea N cycled to the PDV; however, when expressed as a percentage of hepatic synthesis, urea N transfer to the PDV tended to increase from 50 to 64% for SF compared to DR. The latter tendency is similar to the numerically greater values in the present study (54 vs 69% for DR vs SF, respectively; $P < 0.12$; Table 5). The proportions of hepatic urea production transferred to the PDV in the studies by Huntington (1989) and Huntington et al. (1996) of 48 and 50 to 60%, respectively, were similar to the value for steers fed DR sorghum grain in our study.

Urea cycling is important in N conservation for ruminants when N supply is low and also for high-producing and rapidly growing animals. Urea entering the rumen can be utilized by rumen microorganisms to increase synthesis of microbial protein and its flow into the small intestine (Al-Dehneh et al., 1997). Although the total amount of urea N cycled to the rumen (via rumen wall and saliva) was not altered by SF vs DR, 30% more urea N (10 g/d) was transferred through the rumen wall of steers when they were fed SF vs DR (Table 4). Efficiency of gain is consistently improved for feedlot steers fed SF sorghum (Hale, 1980) and SF corn (Barajas and Zinn, 1998; Zinn et al., 1998) compared to steers fed DR grains. It may be that ureolysis by bacteria adhering to the rumen epithelium and resultant capture of ammonia N by rumen microorganisms (Chen and Wallace, 1979) is more efficient than ureolysis and ammonia N capture in the "deep digesta" (Egan, 1980) where endogenous urea N from saliva would be predominantly associated.

A decrease in output of urea N from splanchnic tissues (gut + liver tissues) could result in lower output of urea N in the urine, thus improving conservation of N by the animal. Splanchnic output of urea N (routed to saliva or urine) was numerically lower ($P < 0.17$; Table 4) for SF than for DR. Similarly, Alio et al. (2000) found that feeding SF (average of three flake densities) compared to DR sorghum decreased splanchnic output of urea N.

When expressed as a percentage of N intake, urea N cycled to the PDV was greater (42 vs 29%; $P < 0.05$) and total N (ammonia N + α-amino N) apparently absorbed tended to be greater (70 vs 50%; $P < 0.07$) for steers fed SF vs DR sorghum (Table 5). Similar values for the percentage of N intake cycled to the PDV as urea N have been reported for steers fed a 77% SF or DR sorghum diet twice daily (38%; Alio et al., 2000), steers fed a 78% cracked corn diet twice daily (41%; Reynolds and Huntington, 1988) and 12 times daily (27%; Huntington, 1989), and steers fed 50 to 90% cracked corn diets 12 times daily (28%; Huntington et al., 1996).

Most of the blood urea cycled from the liver to gut tissues is transferred to ruminal tissues. The proportion of PDV urea N transferred through the rumen wall was 77 ± 3% and through the intestinal wall was 23 ± 3% for both treatments (Table 3). Other studies investigating effect of dietary regimen on urea cycling have also reported that most of the blood urea N cycled from the liver to gut tissues is transferred across the rumen wall of steers fed high-grain diets containing ground or cracked corn (Huntington, 1989; Reynolds and Huntington, 1988; Huntington et al., 1996).

Table 5. Urea N balance across splanchnic tissues and in urine of steers fed dry-rolled or steam-flaked sorghum grain diets expressed as a percentage of N intake, N apparently absorbed, hepatic synthesis, or portal-drained viscera (PDV) transfer

Ratio	Dry-rolled	Steam-flaked	SEM	*P*
PDV/N intake	29	42	3	0.05
PDV/AAN and NH_3 N absorption[a]	50	70	5	0.07
PDV/hepatic	54	69	5	0.12
Intestinal/hepatic	10[b]	18	2	0.13
Ruminal/hepatic	46	49	4	0.70
Splanchnic/hepatic	46	30	6	0.13
Intestinal/PDV	19	27	3	0.13
Ruminal/PDV	81	73	3	0.13
Urinary/PDV	63	42	3	0.01
Urinary/splanchnic	68	98	17	0.23
Urinary/hepatic	33	28	3	0.32

[a]PDV = portal drained viscera; AAN = α-amino N; NH_3 N = ammonia N.
[b]Mean is not different from zero ($P < 0.05$).

For SF vs DR, the proportions of hepatic urea N synthesis accounted for by urea N uptake were numerically greater by intestinal tissues (18 vs 10%) but numerically lower for splanchnic release of urea N (30 vs 46%; $P < 0.13$; Table 5). Alio et al. (2000) noted that splanchnic release of urea N (percentage of hepatic production) tended to be decreased in steers fed SF vs DR sorghum diets. The percentage of urea N produced by the liver that was transferred through the rumen wall (48 ± 4%) or transferred to urine (30 ± 3%) did not differ with grain processing treatment (Table 5). The proportion of urea N released by splanchnic tissues accounted for as urea N in the urine (93 ± 17%) also did not differ with treatment. These percentage values for DR (Table 5) are similar to those for steers fed a 78% cracked corn diet (Huntington, 1989). The proportion of urea N in urine expressed as a percentage of urea N transferred to the PDV was decreased ($P < 0.01$) in steers fed SF compared to DR.

In summary, steam-flaking compared to dry-rolling of sorghum grain in 77% grain diets decreased arterial and venous blood concentrations of urea N and increased hepatic uptake of α-amino N. In addition, steam-flaking increased urea N cycling to PDV (gut tissues) and intestinal tissues, which could account for (in part) the decrease in whole-body urea N output in urine in growing beef steers. Whole-body N retention was not altered ($P < 0.24$), even though steers fed SF sorghum numerically retained 5 g/d more N than when fed DR sorghum. Steam-flaking numerically improved ($P < 0.12$) N retention expressed as a percentage of N intake. About 75% of the urea N transferred to PDV was taken up by ruminal tissues, and uptake of α-amino N by ruminal tissues was 30% of the net amount of α-amino N absorbed by intestinal tissues.

Implications

In this study steam-flaking compared to dry-rolling of sorghum grain increased the amount of blood urea N cycling to the ruminal, intestinal, and total gut tissues (reticulorumen and intestines) in growing beef steers. This increase could enhance microbial protein synthesis in the rumen, which may account for some of the enhanced efficiency of feeding steam-flaked corn or sorghum grain to feedlot beef cattle.

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